

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Architecture Program: Faculty Scholarly and
Creative Activity

Architecture Program

9-18-2010

Searching for Innovation Through Teaching Digital Fabrication

Timothy Hemsath

University of Nebraska-Lincoln, themsath3@unl.edu

Follow this and additional works at: https://digitalcommons.unl.edu/arch_facultyschol



Part of the [Architecture Commons](#)

Hemsath, Timothy, "Searching for Innovation Through Teaching Digital Fabrication" (2010). *Architecture Program: Faculty Scholarly and Creative Activity*. 20.

https://digitalcommons.unl.edu/arch_facultyschol/20

This Article is brought to you for free and open access by the Architecture Program at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Architecture Program: Faculty Scholarly and Creative Activity by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Searching for Innovation Through Teaching Digital Fabrication

Timothy L Hemsath¹

¹University of Nebraska-Lincoln, United States

¹(<http://architecture.unl.edu>)

¹themsath3@unl.edu

Abstract. *The use of digital fabrication in the discourse and education of architectural students has become a common skill in many schools of architecture. There is a growing demand for computer-aided design (CAD) skills, computer-aided manufacturing (CAM) logic, programming and fabrication knowledge in student education. The relevance of fabrication tools for architecture and design education goes beyond mere competence and can pursue innovation in what Branko Koleravic (2003) observed, “The digital age has radically reconfigured the relationship between conception and production, creating a direct digital link between what can be conceived and what can be built through “file-to-factory” processes of computer numerically controlled (CNC) fabrication”. However, there has been very little written about what students are actually learning through digital fabrication courses and the relevance of the skills required for innovation in the field of digital fabrication.*

Keywords. CAD; CAM; Pedagogy; Curriculum.

Introduction

To discuss in more detail the didactics of a digital fabrication pedagogy, this paper evaluates innovative student work in digital fabrication collected from two years of teaching at the University of Nebraska-Lincoln (UNL). The course teaches students a CNC skillset in the production of innovative work through the file-to-factory process of CAD/CAM fabrication. The first section will discuss the context of the course and intellectual search for the proper curricular goals and teaching methodologies utilized. Next, a discussion of the student work produced comparing past and current work from the standpoint innovation and the subsequent CAD, CAM knowledge learned. Merging the course work discussion and methods

provides a framework for a digital fabrication pedagogy and highlights the architectural skills students have gained through the course. The paper concludes by reviewing the work from the standpoint of innovation in the field of digital fabrication and showcases how the CAD/CAM pedagogies provide a rich context for student learning and research.

Innovation in the student work and the didactic course design was inspired by the notion that “we can use digital fabrication as a catalyst for design instead of just a means of production. (Cheng and Hegre, 2009)” We too were interested in CNC craft and the workmanship of certainty and risk discussed by David Pye (1968) further defined by Luis Eduardo Boza (2006) where the workmanship of risk “relies on a personal creative knowledge of the tools, materials

and techniques.” The student activities were critical of the production process, fighting against the notion that machine craft removes “risk and the critical creative role of the craftsman/artisan, are taken out of the equation.” (Boza, 2006). The pedagogy and examples of work discussed are investigated for innovation as an ongoing discussion on how the machines can enable, not limit, creative design results.

Digital Fabrication Pedagogy

The digital fabrication course taught at our institution is the first of its kind and the curriculum is derived for our specific equipment and CAD skillset. Additionally, the author/instructor had no prior teaching experience related to digital fabrication. As a result the course development and design was well suited for the University of Nebraska-Lincoln’s peer review of teaching project to benchmark the course goals and outcomes of student learning in a course portfolio [1]. The course has been involved in two years of the peer review project to develop the overall outcomes and refine a research focus specifically on digital fabrication at the College of Architecture. The completion of the peer review of teaching project and course portfolio aided in refining this course’s complexity, clarity and produced transformative ideas for future digital fabrication research.

From this critical activity emerged the course titled, File-to-Factory Digital Fabrication, was modeled after the course content offered at other institutions’ architecture programs, such as MIT, Georgia Tech and Columbia University. The resulting course developed is a three credit hour graduate elective taken by graduate students from the College of Architecture, with backgrounds in design (Architecture, Interior and Landscape Architecture). Students enrolled in the course build on the professional programs strengths and compliments other graduate electives, which focus on craft, materials and fabrication (making of architecture). In this context the digital fabrication elective augments this knowledge and skill-set of making through using digital tools

to design with CAD, translate with CAM software for CNC fabricated form.

Course Objectives

The course goal is for students to synthesize various disparate architectural assemblies and materials with the file-to-factory digital fabrication process in order to understand the making architecture. Achieving this goal enables students to build knowledge of design process from CAD conception to CAM production. The course on digital fabrication expects that students will have an understanding of:

- The Computer-aided Manufacturing processes used in the construction of the physical form of architecture.
- The role of CAD methods, emerging CNC technologies and tools used by fabricators and practitioners in the practice of architecture.
- Materials and methods utilized in file-to-factory digital fabrication.

At the completion of the course, we expect students to be able to:

- Utilize CAD and CAM software in the digital design process to model, rationalize and manipulate form and space.
- Digitally translate and rationalize complex forms and shapes for CNC fabrication.
- Design, fabricate and assemble digitally created form, structure and surface.
- Use advanced fabrication equipment at the College, computer numeric controlled milling, laser cutting and rapid prototyping.

Teaching Methods

Face-to-face contact time with students each week is through a one-hour lecture and four hours of lab time. The lecture is used for discussions related to course goals. The four-hours of lab time is used primarily for skills-based training either through software tutorials, equipment training or work time on projects. As the semester progresses projects gained in complexity the lab time opens up to allow students longer working periods.

The weekly one-hour lecture is used to introduce assignments, review specific topics or case studies, tours or presentations by students covering pertinent course topics. The first assignment was a topical discussion to review various case studies, examples and fabrication methods exposing students to digital fabrication. The topics look critically to fabrication equipments role in architecture to understand how others synthesized various disparate assemblies, and materials into architecture. These lectures provided the opportunity to discuss similarities and differences between analogue production processes (e.g., hand saw) and digital production process (e.g., CNC machines); giving students an understanding of the manufacturing processes used in the construction of the physical form of architecture. The case studies also showed the use of digital processes in producing innovative work in the field of digital fabrication taken from contemporary projects and other research projects. We visited a number of manufacturers where we could learn and share their experiences and fabrication processes with students; allowing the class to discuss the role of digital design methods, emerging technologies and tools used by fabricators and practitioners in the practice of architecture. Other lectures discussed the varied history, theory, materials and methods utilized in file-to-factory digital fabrication.

The lab periods at the beginning of the semester included basic software tutorials and provided a framework for conceptual design strategies for the course assignments. Materials provided in class focused primarily on fabrication and were not planned to cover topics students were expected to know, such as basic 3D solid and NURB modeling, generating surfaces from curves, curve networks, edgesurf, surface offsets, recording history, paneling tools and others. The software tutorial topics we did discuss related to the specific assignment outcomes expected, such as the use of developable surfaces from curves or lofted shapes, and software operations such as unfolding, smashing, framing scripts, paneling tools, sporfing, and others. Additionally, in-class and

on-line tutorials (software and hardware) equipped the students with a working knowledge to design and use CNC equipment to fabricate their designs. Transitioning from year 1 to year 2 of the course, software topics were covered more aggressively in year one of the class because of students' CAD skill levels. The CAD methodologies reviewed were critical to understand form and geometry through the analytical methods provided by the software for CNC fabrication. In the second year, the class focused specifically on CAD tutorials because students were more skilled than previous years and there was less time available due to the increased complexity and specificity of student work. This new richness in work required more in class discussion for dissemination amongst the students in the course of the lessons students were learning.

Other lab periods involved hands-on training tutorials for specific equipment in our fabrication lab, such as the laser cutter, 3-axis CNC milling machine and 3d printer. Tours and training were coordinated with the Engineering College for exposure to their CNC equipment and other external local manufacturers with large-scale industrial production tools and equipment. Tours showed students the possibilities of what can be made with the equipment, the diversity of material choices and the necessary planning required in the production of the production code, or numeric language the machines use.

The next teaching method utilized project based learning to give students hands-on skills related to complete the assignments. A series of small projects were prepared based on three areas of digital fabrication; ornamental tooling, tectonic jointing and surface/structure integration, which evolved from the lecture and reading content over the past week proving a framework for exploration. The projects challenged students to utilize the file-to-factory process of digital design-to-fabrication to conceive and produce architectural form within these specific areas. In these assignments, students developed the ability to use modeling software in digital design process, to analyze, virtually manipulate and generate

form and space. They engaged the file-to-factory process to rationalize complex forms and shapes for fabrication through specific CAM language. The projects intentionally fed these specific design outcomes related to digital fabrication to introduce the basic fundamental skills necessary for the fabrication and assembly of digitally generated form, structure and surface.

The course was intentionally structured, lecture – lab – reading – tours, to provide adequate scaffolding to support student's learning in fabrication and their understanding in the influences of digital fabrication processes in their design. The tools they used shaped their representations and design outcomes. There are many skills students possess in CAD, however at the start of the course they lacked adequate knowledge and experience to output their designs effectively and accurately with CNC tools.

In my search for innovation, in year 2 of the course we varied the physical materials used and the fabrication equipment from project to project in order to develop expertise, complexity and advance their skills in 3-axis computer numeric controlled milling, laser cutting and rapid prototyping (3d printing). Students would through each of the three assignments move from the CNC milling machine to the laser cutter to the 3d printer allowing a larger class to not step on each others toes, or take away equipment time from other students in the college, and most importantly develop different and diverse expertise which could be shared in class discussions. In this activity, students were able to develop specific expertise related to the assignment topic empowering them to help others and be leader in the course. This method was successful in increasing the complexity and diversity each assignment from year 1, enabling students to be more innovative and not repeat previous fabrication operations but learn something new within each assignment, while building on knowledge developed by their peers.

Coursework Review

As the challenge in year 2 of the course, the course didactics were modified to critically enable a CNC craft introduced above. A large change was necessary to introduce and provide a clear theoretical overview of digital craft and tectonics through readings and case studies. Transitioning into year 2 of the course, the workmanship of certainty enabled by the production machines was framed as a critical exploration of a machine craft or what we called 'tooling'. Our tooling was in part derived from Neil Leach's Digital Tectonics (2004), which "addresses this new sensibility within the building industry, and explores its dependence upon digital technologies." The following work will highlight two years of student projects elaborating on the changes made from year one to year two in the search for innovative digitally fabricated work. Each assignment's content was developed in more detail from the previous year of the course to find specific areas of innovation and creative exploration by students.

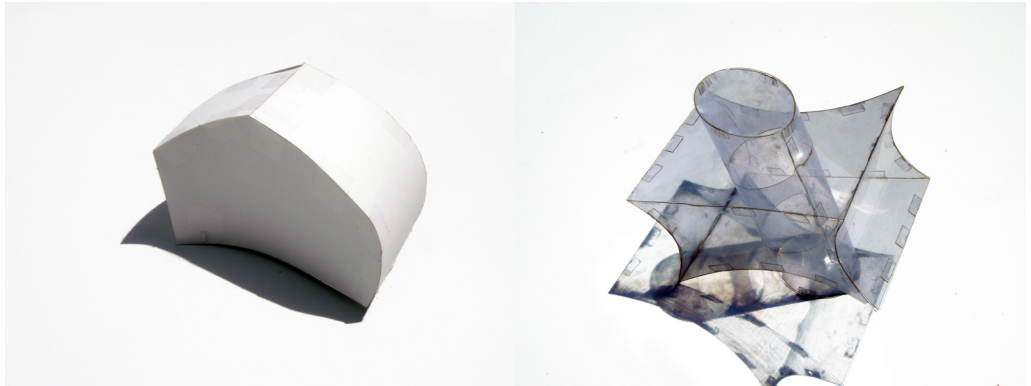
Year 1 – Interlocking Boxes Assignment

The course began with a basic, challenging and rigorous project building on the students existing knowledge with the use of the Laser Cutter developing expertise in subtractive fabrication. The challenge in this assignment was to deal with joint tolerances and the material thickness between the various sides of boxes, pieced together like a 3d puzzle.



Figure 1
Plexiglas jointed box.

Figure 2
Developable forms from paper and acetate.



Year 1 – Developable Form Assignment

Next, students moved from rectilinear shapes to curved forms, developable or ruled surfaces, with several new materials on the laser cutter. Utilizing the laser cutter built on their past experience. Similar to the previous assignment careful attention as required to properly join the various surfaces together. The assignment increased in complexity of the formal composition by requiring the translation of developable surfaces into 2d shapes and assembled into a final form.

Year 1 – Mold Making Assignment

Students were asked to use the CNC milling machine to subtract material from a 2" piece of foam

to produce a surface. The machining required both horizontal roughing (shown in unfinished example on left) and parallel finishing requiring a tool change. The parts were to fit within a 12" square and cut from a larger 2'x4' piece, requiring students to set their x,y & z coordinates for proper output.

Year 1 – Mold Making Assignment

Students were next asked to use the foam part to cast a concrete block to introduce formative manufacturing techniques. This assignment tied to the work completed in the previous assignment.

Year 2 Changes

The projects highlighted in Year 1 involved students

Figure 3
CNC molds made by Jamison Burt (left) and Laura Broderson (right).

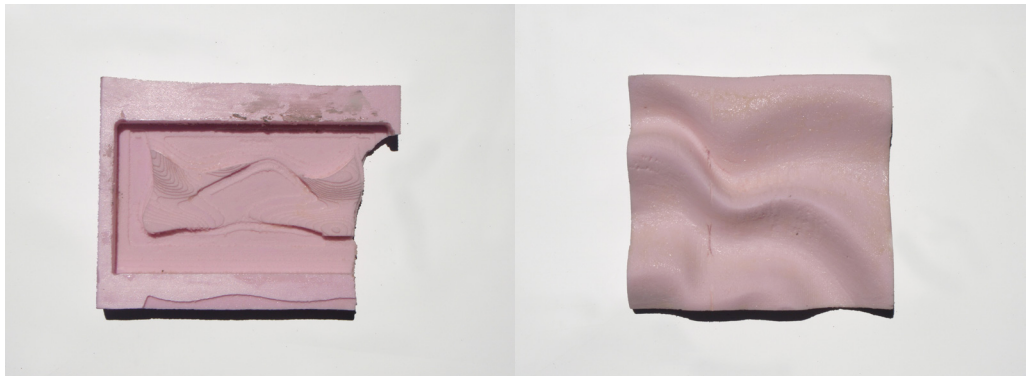
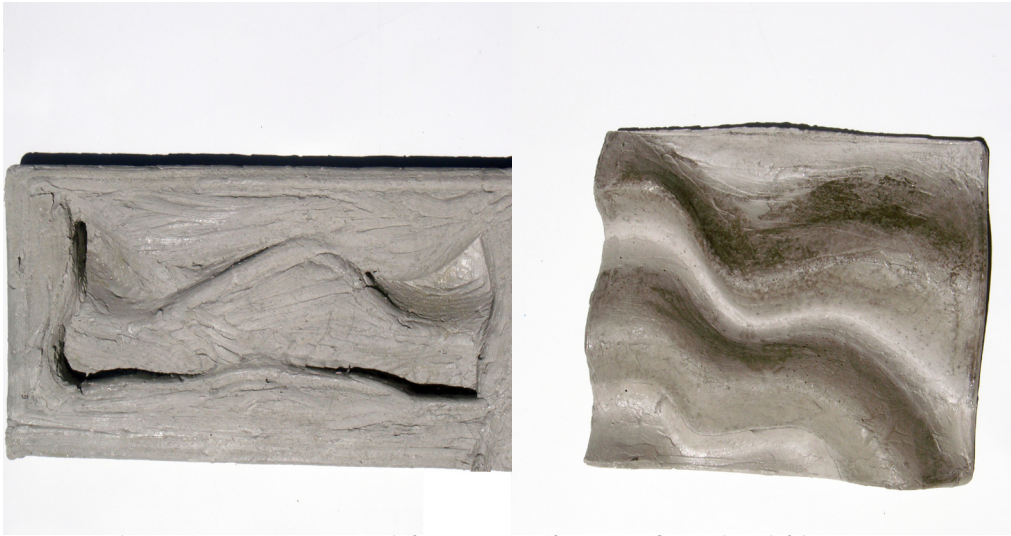


Figure 4
Concrete tiles from molds by
Jamison Burt (left) and Laura
Broderson (right).



generating basic geometries in CAD differing in complexity and fabrication approaches. The year 1 assignment examples highlighted were not repeated in year 2 because it was thought that the surface/structure assignment (below) completed both years, could produce comparable student learning experience. Additionally, year 2 students were more experienced with CAD and CAM and these assignments were not as challenging, innovative or novel as those assignments developed for year 2 described next.

Year 2 - Ornamental Tooling

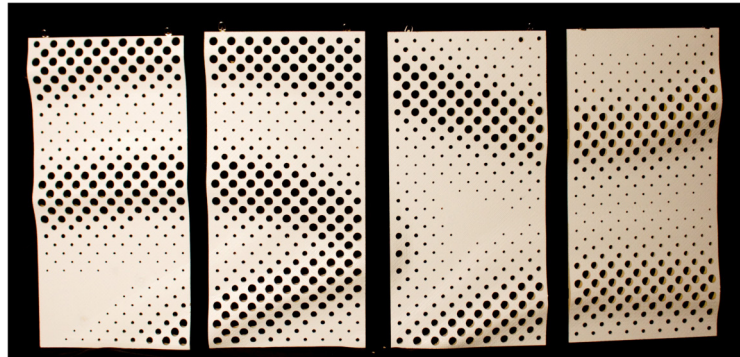
Our first major assignment focused on the generation of ornament, intended to be similar to that of Bernard Cache's *Objectiles* (Kolarevic, 2003), or Breen's *DigiTile Project* (2007). The assignment was the students' first exercise using the equipment and as such the challenge was to develop ornament specific to the tooling methodology of the machine itself. Each fabrication method, 3d printing, Laser Cutting or CNC milling, has a specific logic or personality students sought to embody in their ornament. To motivate students in this assignment we discussed the specific tooling for each machine and presented research completed, which generated ornamental

affects specific to digital fabrication. For instance, the 3axis CNC milling machine tooling we discussed looked at how various subtractive machining operations could create affects based on tool step over or step down and specific to the tool used itself within 2, 2-1/2 and 3 axis machining. The two examples below in Figure 1 shows how 2 axis engraving or profiling combined with 2-1/2 axis surface treatments could generate surface patterns.

Year 2 - Tectonic Jointing

This assignment specifically challenged students to develop joints that were specific to the fabrication logic of each machine. Similar to developing tooling logic for the generation of ornament, the joints should be expressive of a digitally fabricated tectonic in the joint itself. We looked at previous work completed by Prof. Jochen Gros and Designer Friedrich Sulzer [2] in the generation of wood joints specific to CNC machining and Axel Kilian's puzzle like surface joints. Kilian (2003) observed that "the potential for the creative reinvention of details originating in conventional craft in a CNC process. This can be accomplished through generative techniques where a customized solution for each detail is produced.

Figure 5
Ornamental Panels by
Brandon Beatty and Nathan
Holland.



However, few designers have explored these possibilities.” In our case we were concerned more with the specificity of the CNC fabrication methodology to produce the joint in lieu of the customizable application of the joint itself. The two rotational elbow joints examples here show a continuation of the CNC wood joint exploration and the innovative work produced by students.

Year 1 and 2 - Surface/Structure Integration

In the final small-scale assignment we looked at the integration of the surface and structure of a digitally generated form. The topic itself while not specifically innovative is necessary exploration were students can apply lessons from the previous two assignments learning from their successes and failures. The project involved the creation of a double curved surface in CAD and the rationalization of this surface

into a fabricated structure and cladding (skin). The assignment embodies the challenge of how to rationalize the surface for fabrication whether through panelization, subdivision into developable surfaces or formed by casting. Next, the challenge is how to connect the skin with a support structure fabricated with another CNC logic whether subtractive, formed or additive methods. To assist in the assignments success, basic CAD tutorials were covered extracting isoparametric curves and frame generating scripts from NURB surfaces.

The student examples provided here contrast those from year 1 (Figure 7) of the course and year 2 (Figure 8). In each case, students grasped quite effectively the complexity integrating a skin and structure. Year 1 work completed by Brian McCracken was innovative in the panelization of the surface with grasshopper and custom bitmap structure, however

Figure 6
CNC wood joints by Ashley
Byars, Ryan Huber and Carl
Rottinghaus.



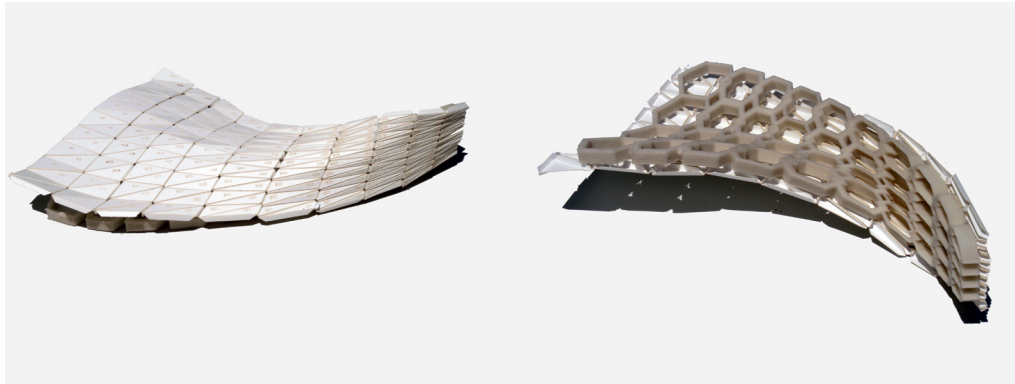


Figure 7
Year 1 Surface/structure inte-
gration by Brian McCracken

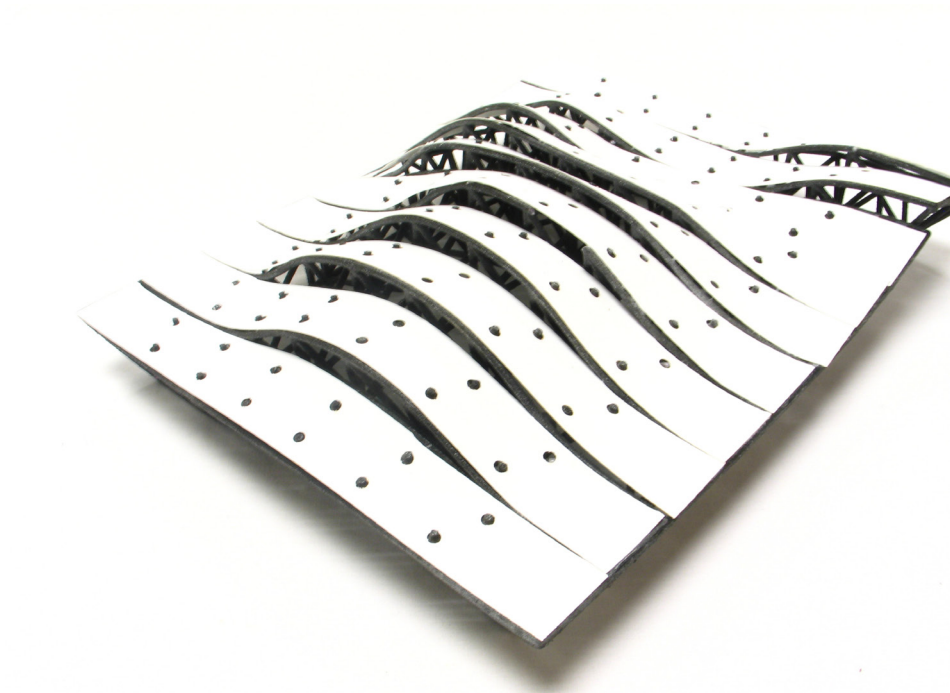


Figure 8
Year 2 Surface/structure in-
tegration by Brandon Beatty
and Nathan Holland.

failure did occur in the disconnect of the structure from the skin. Material thickness was not considered in the triangular pieces of paper used to construct the skin. Whereas, in year 2 the project completed by Brandon Beatty and Nate Holland adequately accommodates this difference and incorporates attachment pegs for the laser cut paper skin attached to the 3d printed space frame structure. Producing a novel solution through customization of the CAD script and 3dprinted CAM structure.

Conclusion

In searching for a concise academic pedagogy for digital fabrication, making visible both the success and failure of student work from year 1 to year 2 highlights improvements made to the course that improved teaching efficacy and student learning. Reflecting on innovation as discussed earlier, the conclusion made following year 1 was the need to connect a particular research focus on digital ornament and tectonics which involved a stronger linkage between the machine tooling and the production of architectural form. This connection was made through the use of CNC tooling taken from what Greg Lynn (2002) describes, “to designing moiré patterns of tool paths there is also the potential to map relief patterns on the surface that get accentuated by the tooling.” We considered tooling as a digital tectonic derived from the CNC machine logic and CAM production process itself. A specific didactic strategy was used to expose students to various CNC machines and their tectonics through each assignment. The student work reviewed provides proof of tooling. Another validation of the didactic approach can be witnessed in comments from one student “I now know more about all of the specifics you must consider when using CAD/CAM processes; to consider tolerances inherent in the machine and the material. I also had little experience of using all of the machines prior and now have a better understanding on each.”

Overall the course in year 1 was successful,

however, there were many areas of improvement made in year 2 suggested by students to streamline the course and improve the quality of work. Several logistical changes were made involved altering the course scheduling for tours and lectures to earlier in the semester to highlight the possibilities of CAM and related design implications. Year 2 sought to improve innovation in digital fabrication by developing stronger linkages to built examples showing more examples of innovative architectural precedents in the course, integrating more clearly theoretical readings and building a body of CNC fabrication expertise from assignment to assignment and developing knowledge in the college to facilitate the investigation of a digital tectonic through our course blog, <http://www.unldfc.blogspot.com>. Student commented, “I have an understanding of multiple programs (rhino, CAM, Illustrator) that I previously didn’t. I have also been able to think in a digital way that allows me to understand the creation of complex forms and surfaces.” Suggesting that the search for innovation in the course was also successful in meeting a two course objectives for students to first; digitally translate and rationalize complex forms and shapes for CNC fabrication and second; design, fabricate and assemble digitally created form, structure and surface.

Showing how assignments changed from year 1 to year 2 of the digital fabrication course demonstrates how critical reflection on a specific didactic strategy is successful in producing innovation in digital fabrication. The course discussed in this paper successfully articulated the “connection” between design and production for student learning and the value of file-to-factory digital fabrication. Student knowledge and design capacity is critical to the built world that is constructed, designed, engineered, and empowered by the manufacturing methods and the design tools used. Therefore, the content of this course challenged students to expand their tectonic abilities in the creation of architecture through

seeking innovative work and in-depth understanding of digital fabrication.

References

- Boza, LE 2006, '(Un) Intended Discoveries Crafting the Design Process', *Proceedings of the 25th Annual Conference of the Association for Computer-Aided Design in Architecture*, pp. 150-157.
- Breen, J and Stellingwerff, M 2007, 'The DigiTile Project, Conceiving, Computing and Creating Contemporary Tiling Prototypes Using Computer Aided Modelling Techniques', *Proceedings of the eCAADe Conference*, Frankfurt am Main, pp. 59-66.
- Cheng, NY and Hegre, E 2009, 'Serendipity and Discovery in a Machine Age: Craft and a CNC Router', *Proceedings of the 29th Annual Conference of the Association for Computer Aided Design in Architecture*, Chicago, Illinois, pp. 284-286.
- Kilian, A 2003, 'Fabrication of Partially Double-Curved Surfaces out of Flat Sheet Material Through a 3D Puzzle Approach', *Proceedings of the Association for Computer Aided Design in Architecture*, Indianapolis, Indiana, pp. 75-83.
- Kolarevic, B (ed.) 2003, *Architecture in the Digital Age: Design and Manufacturing*, New York, NY : Spon Press.
- Leach, N, Turnbull, D, and Williams, C. (eds.) 2004, *Digital Tectonics*, John Wiley & Sons Ltd, United Kingdom.
- Lynn, G and Rashid, H 2002, *Architectural Laboratories*, NAI Publishers
- Pye, D 1971, *The Nature and Art of Workmanship*, London, Studio Vista; New York, Van Nostrand Reinhold.
- [1] <http://www.courseportfolio.org>
- [2] <http://www.flexiblestream.org/Digital-Wood-Joints-001.php>